Teaching rates of reaction post-16, part 2

Whether they're natural or synthetic, catalysts are everywhere. They're essential for life and are used in numerous manufacturing processes to increase production rates and cut costs. You might be familiar with the use of catalysts in the production of ammonia and sulfuric acid, but did you know that chemists are also developing a range of catalysts to help clean pollutants in our environment?

Catalysts may also play a part in answering that famous big question: how did life begin? Some scientists have proposed that the answer lies with common mud, or more accurately the clay minerals in mud, which can act as catalysts.

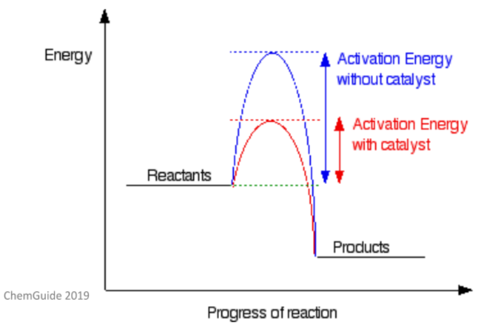
What students need to know

To understand the role that catalysts play, students need a good understanding of:

- Activation energy and the interpretation of enthalpy profile diagrams and Maxwell Boltzmann distribution curves
- The rate equation: rate = $k[A]^m[B]^n$, where m and n are the orders of reaction for reactants A and B, respectively, and k is the rate constant
- The Arrhenius equation, which shows the link between the rate constant, activation energy and temperature: $k = Ae^{-Ea/RT}$, where A is the Arrhenius constant, E_a is the activation energy and T is the temperature in kelvin
- How to manipulate and interpret the Arrhenius equation with experimental data to show how changes in temperature and the addition of catalysts affect the activation energy and rate constant. $\ln k = \ln A - Ea/RT$

Threshold concept

A key concept is the idea that catalysts provide an alternative reaction pathway with a lower activation energy. They do this by producing an alternative transition state or intermediate to that in the catalyst-free reaction. This may be due to adsorption of molecules onto a catalyst's surface or active site, or a redox reaction involving different oxidation states. Either process results in a lowering of activation energies.



Common misconceptions

You may find that some of your students hold one or more of these common misconceptions.

- Catalysts break chemical bonds. They don't. A catalyst works by providing an alternative reaction pathway, with a lower energy of activation (E_a)
- Catalysts increase the yield of the product. Looking at how catalytic converters in cars work is useful here, and provides a suitable topic for further discussion
- In a reversible reaction at equilibrium, catalysts only affect the rate of the forward reaction. If this was true, the position of the equilibrium would also be affected. Remind your students that, at equilibrium, the rates of the forward and reverse reactions are the same. Try out some of these activities
- Catalysts 'are not involved' in chemical reactions. This misconception arises because many catalysts can be recovered, chemically unchanged, at the end of a reaction. The catalytic oxidation of potassium sodium tartrate (aka traffic lights) can be used to illustrate that catalysts are involved in reactions – the solution reverts from green back to the original pink colour. At pre-16 level, students are told that the mass of MnO_2 before and after catalytic breakdown of H_2O_2 is the same

Ideas for your teaching

When it comes to the big questions, catalysts may have some of the answers. Use these exciting contexts to get your students hooked.

Mud and life on Earth

One of science's biggest questions is 'how did life on Earth begin?' Well, the answer might involve clay – a major constituent of mud – catalysing the synthesis of the precursor molecules to life. This idea, first suggested in the 1920s, is now backed up with modern experimental data (Ponnamperuma et al. 1982, Biondi et al., 2007 and Hao et al, 2019).

A clay's porous structure gives it a massive surface area, covered in potentially catalytical active sites. There's plenty of room for lots of organic molecules to find one of these active sites and undergo a reaction, yielding key biogenic molecules such as amino acids, polypeptides and even RNA. What's more, clay's sponge-like structure protects reagents and products from degradation from UV light – a big factor in Earth's early history.

Can catalysts can help clean up our planet?

• Plastic waste can now be efficiently converted into methane using a ruthenium-based catalyst. This new technology could help mitigate the planet's growing plastic-waste problem while simultaneously producing methane, for use as a fuel or chemical feedstock, in a more environmentally friendly way than fracking.

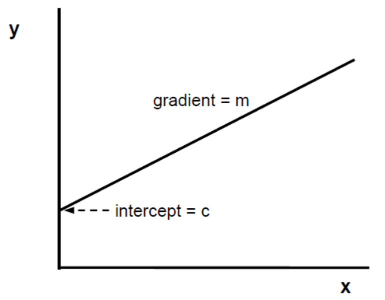
Researchers have found and developed an efficient, inexpensive new catalyst for turning atmospheric carbon dioxide into jet fuel. Such a net-zero fuel could be a major breakthrough in the fight against climate change.

Students can also be Introduced to the types of careers that employ catalysis. A wide range of examples can be found on the STEM Learning website (www.stem.org.uk/stem-careers).

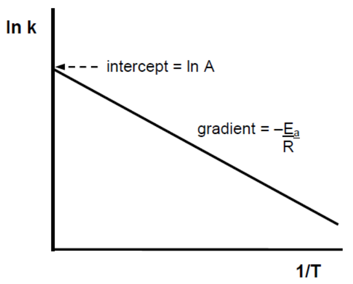
Linking the pieces of the Arrhenius equation

Use graphs to help your students make the links between the rate constant, reaction temperature and activation energy. For example, the natural log form of the Arrhenius equation equates to the equation of a straight line. Remind students, of the simple algebraic equation y = mx+ c, before presenting them with the Arrhenius equation, in the natural logs format. It Is Important to negative gradient of the line results In the line sloping In the opposite direction.

$$y = mx + c$$



$$\ln k = -\frac{E_a}{RT} + \ln A$$



Download the addition resource, which shows a possible teaching sequence and graphical progression of key ideas in rates.

Get practical

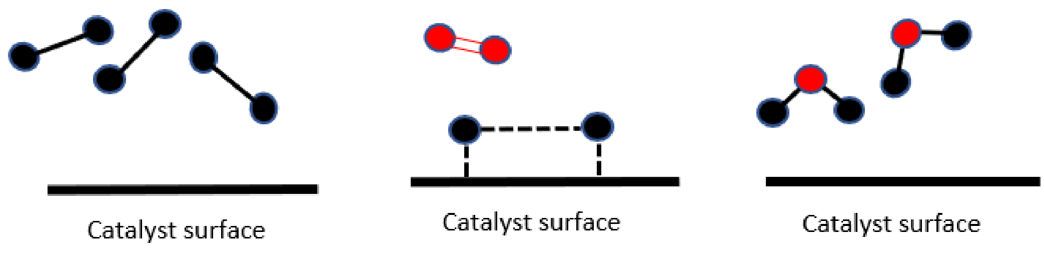
It's always good to use practical activities to re-enforce student ideas. Why not check out our practical videos or have a go at the catalysis of a sodium thiosulfate and Iron(III) nitrate reaction with your students.

Assessment

A more creative way to assess whether students understand a concept is for them to apply their knowledge to solve a problem or to interpret and explain something. Here are four ideas to get you started.

1. Watch the video of Rochelle's salt reaction. Can students explain what evidence suggests that the reaction is catalysed?

2. Ask students to describe and then explain what the following diagram depicts.



3. The following equations can be presented to students. Ask them to identify what represents the catalysts and what represents a transitional or intermediate state. What are the products? Can students write the overall equation for the reaction?

$$A + B \rightarrow C + D$$

$$D + E \rightarrow B + F$$

4. Now challenge students with this reaction equation. Can they identify the intermediate and catalyst species? Can they explain their choices?

$$H_2O_2 + I^- \rightarrow H_2O + IO^-$$

$$IO^- + H_2O_2 \rightarrow H_2O + O_2 + I^-$$

Answers included in additional teacher resource.

Take-home points

• When teaching rates of reaction, be creative. Use up-to-date contexts and, where possible, include relevant careers to capture student interest. Catalysts are, and will remain, at the cutting edge of science and technology. *Chemistry World* is a great source of information

• Be aware of common misconceptions associated with this topic and use questioning to identify them in your students. Challenge these ideas through a series of classroom activities.

• When it comes to assessment, challenge students to solve a problem or interpret and explain a reaction.

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